NATIONAL INSTITUTE FOR NUCLEAR AND HIGH ENERGY PHYSICS

ASR-S-001

# REQUIREMENTS FOR THE MANUFACTURING AND SPACE QUALIFICATION OF ALL THE PRESSURIZED WELD JOINTS IN THE AMS-TTCS EVAPORATOR.

Bart Verlaat

Revision B, 2 September 2003

Change Log:

*Issued:* *13 March 2003*
*Revision A:* *9 July 2003*

NIKHEF

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THE NETHERLANDS

# SUMMARY

This document contains the requirements for the manufacturing and qualification of all the pressurized weld joints in the AMS-TTCS evaporator. The procedure herein is developed at the Shell Research Laboratory and it is agreed upon with welding specialists at NASA-JSC and LMCO.

CONTENTS

# 1. Introduction to the AMS-TTCS

## *1.1. Introduction of Alpha Magnetic Spectrometer (AMS)*

The Alpha Magnetic Spectrometer (AMS) is a space born detector for cosmic rays built by an international collaboration. AMS will operate aboard International Space Station (ISS) for at least 3 years, collecting several billions of high-energy protons and nuclei. Its main goal is the search for cosmic antimatter, which is for anti-helium nuclei primarily. A first version of the detector, known as AMS-01, flew aboard the Space Shuttle Discovery during the STS-91 mission (2-12 June 1998), collecting about hundred millions of cosmic rays. The precursor flight results confirmed the main ideas of the project and gave useful suggestions for further development. For the ISS mission, the detector will be slightly different in concept, but much better in resolution. In fact, AMS-02 will be an "improved" version of AMS-01, with a more powerful cryogenic magnet and a few new sub-detectors.

## *1.2. Tracker Thermal Control System*

A collaboration of NIKHEF, University of Geneva and NLR are developing a mechanically pumped two-phase carbon dioxide loop for the thermal control of the AMS Silicon Tracker, one of the most important AMS detectors. The Tracker, located inside the vacuum case, is surrounded by the cryogenic magnet, which is not allowed to receive any heat from inside. Moreover the Tracker has rather severe requirements regarding spatial and temporal temperature gradients. This and the existing complicated three-dimensional configuration, requires that the power dissipated in the Tracker (around 200 W) must be removed by means of an active mechanically pumped two-phase loop.

This two-phase loop named Tracker Thermal Control System (TTCS) incorporates long evaporators, picking up the heat from the multiple heat input stations evenly distributed over the 8 silicon planes. The heat is transported to a condenser connected to a heat pipe radiator. The liquid is transported back to the evaporator by means of a mechanical pump. Figure 1.1 shows the TTCS installed in AMS, Figure 1.2 shows details about the TTCS evaporator.

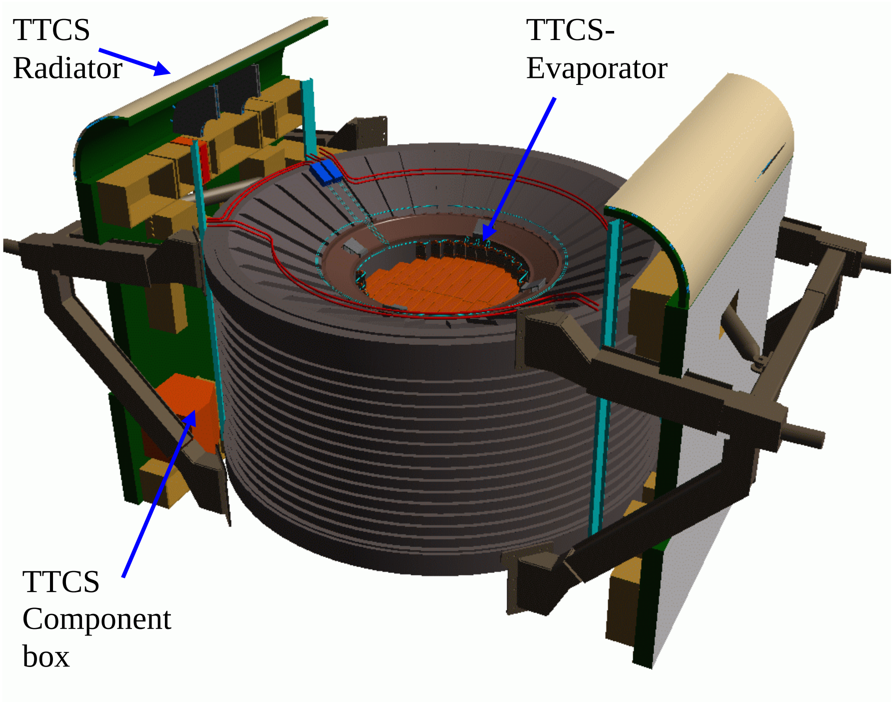



*Figure 1.1: TTCS overview in AMS.*

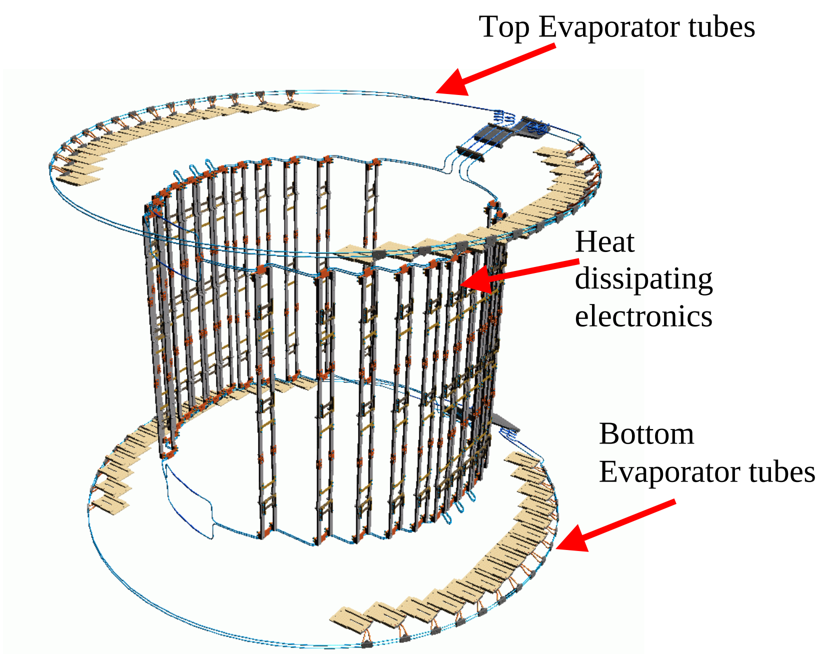



*Figure 1.2: Evaporator overview.*

## 2. Evaporator tube welds overview:

The AMS-TTCS evaporator pressurized volume is a circa 10 m long 2.6mm inner diameter tube. The evaporator tube is made of 2 different types of seamless stainless steel CRES 316L tubes. The copper bridges are soldered to 3mmOD / 2.6mmID tubes. These 3mm tubes are welded to 4mmOD / 2.6mmID with a laser. This thicker tube section is applied to make standard gas tungsten arc wire (GTAW) orbital welding possible for joining the several evaporator sections together.

The evaporator tube is redundant, 2 separated tube circuits run next to each other. Only at orbital welding locations the inter tube spacing is increased. The minimum spacing for orbital welding access is 35mm.

There are 3 sections of the 3mm tubes. Figure 2.1 shows these 3 sections. Each section is laser welded to the 4mm tubes on both sides, this laser welded thicker part we so-call weld connectors. This welding of the weld connectors occur before any bending or soldering will take place to a straight pipe of specific lengths. The concept of the weld connector is given in figure 2.2 and the dimensions for the straight sections are given in drawing ASM004, RevisionB. (See appendix I)

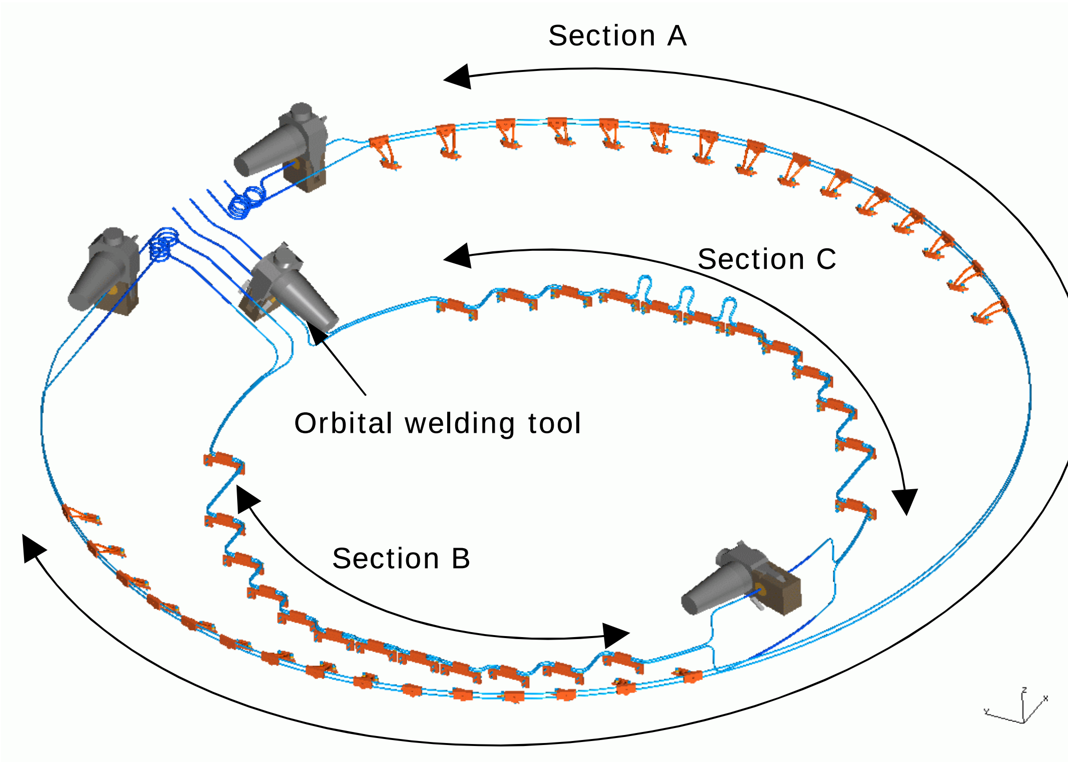



*Figure 2.1: Evaporator set-up including the orbital welding locations.*

Once the individual sections are bend and soldered they will be assembled in a support jig which will be used for transport, installation and welding. The weld connectors of section B and section C are welded directly together. The connection from section A to B has intermediate tubes with the same dimensions as the weld connector (4mm OD x 2.6mm ID). Also the in and outlet tubes connected to section A and C are extra welded tubes of the same dimensions. Drawing ASM001, Revision B shows all the weld locations in the TTCS evaporator.

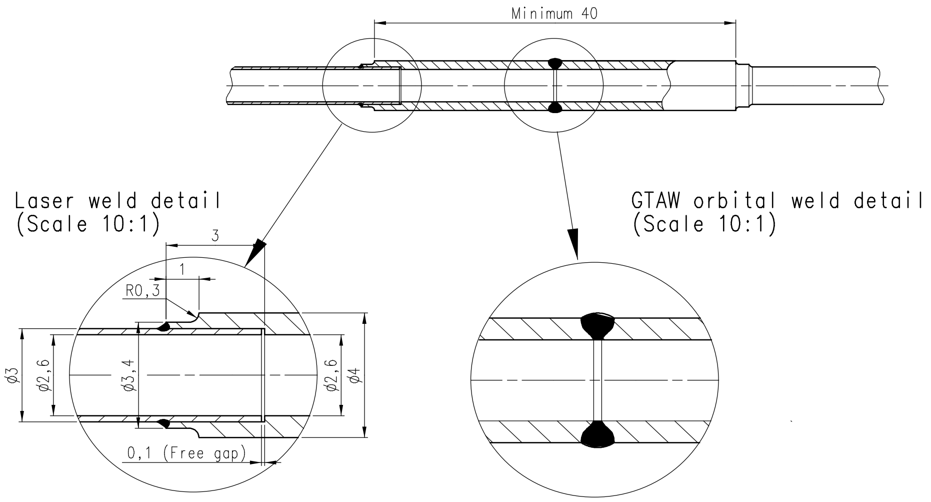



*Figure 2.2: Weld connector concept*

The weld connectors are made longer than needed in the evaporator. The sections will be delivered for orbital welding with the extensions overlapping. It is up to the weld fabricator to cut and flatten them for an orbital GTAW weld which full fills the specs of this document.

# 3. Welding equipment.

The welding of both laser and orbital welding will take place at the Shell Research Laboratory in Amsterdam. The laser welds are made with a Haas™ Neodymium-YAG pulsed Laser. Argon backing gas is used to prevent corrosion, no material addition is made.

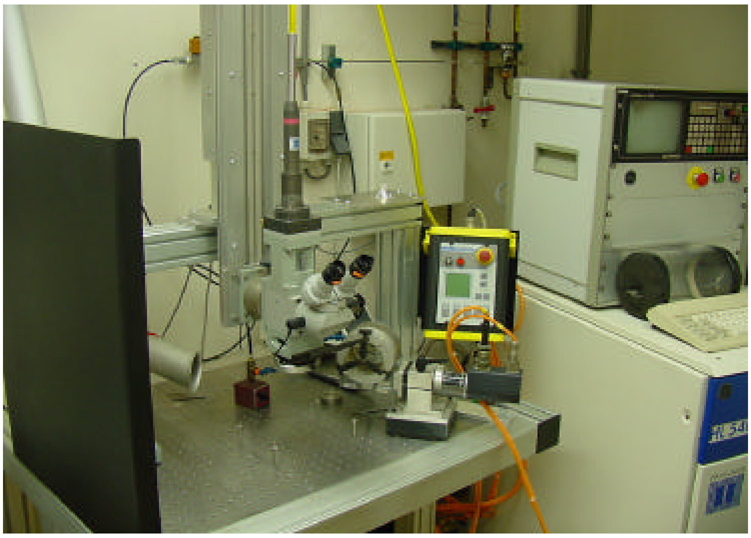


*Figure 3.1: Laser weld apparatus at the Shell Research Laboratory*

The orbital welds will be made with a Swagelok/Cajon™ orbital welding system. The Shell system includes the following hardware:

- Welding head:  Cajon™ CWS-5H-B
- Fixture block: Cajon™ CWS-5TFB
- Collets: Cajon™ CWS-5UCI-04mm

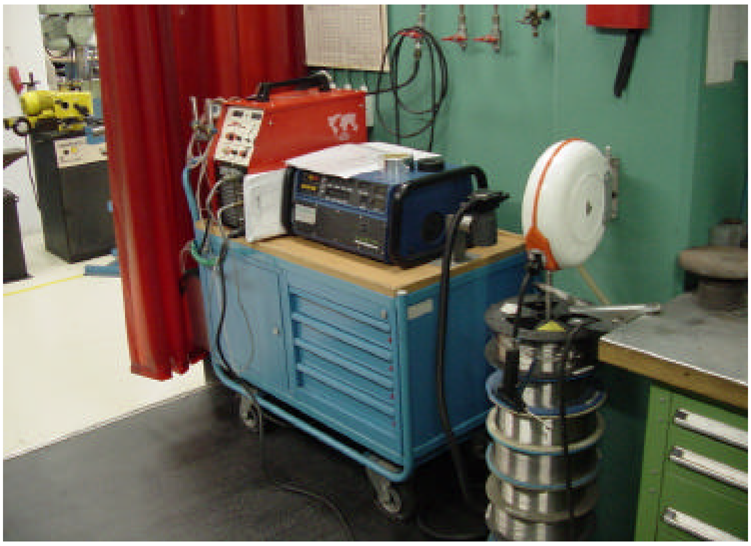


*Figure 3.2: Swagelok orbital weld apparatus at the Shell Research Laboratory*

# 4. Weld process requirements

## *4.1 Weld qualification*

The TTCS evaporator welds will be designed, manufactured, tested and inspected to NASA document: PRC0010, weld class B. Together with NASA engineers, a modification of the test and inspection procedure is agreed. No dye penetrate is required, this modification to the requirements is documented in the attached email communication, which serves as a waiver to the PRC-0010, Rev. A; 8.4 reference (Email communication is included in appendix II).

Although document PRC-0010 is written only for GTAW and PAW processes. We agreed with NASA engineers to use it as the requirement document for laser welding too. Laser welding is so far an unused technique within NASA, at which no specific requirements are available. Next to the production of the flight hardware welds, pre-weld and post-weld samples will be made for extensive testing. These welds shall be made at the same time and with the same machine properties as the flight hardware welds. Due to the controlled process parameters, these pre- and post-welds are considered the same as the flight hardware welds. Some of these welds will undergo destructive testing. A digital copy of PRC-0010, Rev. A is available at:

http://www.nikhef.nl/pub/departments/mt/projects/ams/SiTracker/EvaporatorTubeWelding/PRC0010_RevA.pdf

For each weld type 10 pre-weld samples and 3 post-weld samples shall be made. 5 pre-weld samples shall be made with a “limit low” heat input setting and 5 of them with a “limit high” heat input setting (PRC-0010, Rev A; 6.2.1.2). The limits of the “low” and ‘high” heat input shall be defined by the fabricator in the widest range possible, where low limit heat input shall still penetrate the wall thickness (in case of GTAW) and the high limit still gives a satisfactory weld. The aim of the range shall be in the order of ±10%, but this is no hard requirement. The flight hardware welds shall be made with the nominal power setting. In this case the flight welds are qualified for power fluctuations in the welding apparatus between the low and high limits. 3 Post-weld samples shall be made with the nominal power setting to show the over time process stability. As said in chapter 2, the tubes for GTAW welding will be delivered overlapping. The fabricator shall cut these tubes to length. Since normal machine turning is not possible a special flatten technique shall be used. The same flatting technique shall be used for all the weld samples (pre-, post- and qualification welds) as well.

From both pre-weld sample series 1 weld shall be cut longitudinally by wire spark cutting and 1 shall under go a pressure burst test. The remaining weld samples will be send by NIKHEF to LMCO for additional verification.

## *4.2. Welding procedure specification.*

The welding process shall be documented in a WPS (Welding Procedure Specification). The WPS shall be reviewed before the production of the actual flight hardware (PRC-0010, Rev A; 6.2.1). The PRC-0010 procedure was not followed at the time the test samples (see test report in appendix IV) were made. Therefore a requalification of the welding process is required (PRC-0010, Rev A; 6.2.3).

Requalification requires the welding of only 2 samples of each weld, 1 at “limit-low” heat input setting and one at “limit-high” heat input. The requalification weld samples shall be subjected to a visual inspection and volumetric NDE. An example of a WPS is given in appendix III. An editable copy in PowerPoint format can be downloaded at:
http://www.nikhef.nl/pub/departments/mt/projects/ams/SiTracker/EvaporatorTubeWelding/WPS.ppt

## *4.3. Procedure qualification record*

Welding results (all requalification, flight hardware and post and pre-weld samples) shall be documented in a Procedure Qualification Record (PQR). An example of a PQR is given in appendix III. An editable copy in PowerPoint format can be downloaded at:
http://www.nikhef.nl/pub/departments/mt/projects/ams/SiTracker/EvaporatorTubeWelding/PQR.ppt

## *4.4. Flight hardware weld testing*

### *4.4.1. Proof pressure tests*

All flight hardware will undergo a proof pressure test and a visual inspection of the welds using magnification glasses. The required proof pressure is 1.5x MDP (Maximum Design Pressure). The MDP is 160 bar and the proof pressure is 240 bar. The proof pressure may not show yielding to the hardware.

The proof pressure is applied to the flight hardware with manually compressed liquid $CO_2$ at room temperature. This proof pressure will be applied to the individual straight 3 mm tubes after the laser welding of the weld connectors. Once the sections are joined together with orbital welding, the complete evaporator will be proof pressurized again. Once installed in AMS, the complete TTCS including the evaporators will be proof pressure tested for a last time. Each flight hardware weld in the evaporator will under go at least 2 proof pressure test. The laser welds even 3 times.

### *4.4.2. Leak integrity tests*

Each weld will be leak tested after the proof pressure test with a helium leak detector. A leak tightness of 10-8 mbar*l/s for helium is required. The complete evaporator assembly will undergo as well a pressure decay test. The applied proof pressure will remain in the evaporator for at least TBD days. A pressure decay of TBD bar is allowed.

# 5. Weld quantities.

The total needed welds for flight hardware production and qualification is listed in the tables below.

## *5.1. Flight hardware welds*

The following flight hardware welds quantities are required:

- Laser welds: Qty= 48 (including spares, see table 5.1)
- Orbital welds: Qty=20

An overview of the weld locations is given in drawing ASM001, Rev. B

*Table 5.1: Evaporator sections with laser welded weld connectors:*

| Section # (Figure 2.1) | A | B | C |
|---|---|---|---|
| Dimensions according to ASM004, Rev B. | ASM004-2 | ASM004-1 | ASM004-1 |
| Nominal quantity | 4 | 4 | 4 |
| Spare quantity | 4 | 4 | 4 |

## *5.2. Qualification welds*

The minimum required number of qualification welds needed to qualify the welding process is given in table 5.2.

*Table 5.2: Qualification welds quantity overview:*

<table>
<tr><td rowspan="2"></td><td colspan="2">Pre weld samples</td><td>Post weld samples</td></tr>
<tr><td>”Low limit” heat input setting</td><td>”High limit” heat input setting</td><td>Nominal heat input setting</td></tr>
<tr><td rowspan="3">Weld sample Dimensions according to drawing ASM004-3, Rev. B</td><td>1 logitudinal cut sample</td><td>1 logitudinal cut sample</td><td>3 samples</td></tr>
<tr><td>1 burst test sample</td><td>1 burst test sample</td><td></td></tr>
<tr><td>3 normal samples</td><td>3 normal samples</td><td></td></tr>
<tr><td rowspan="3">GTAW orbital weld type</td><td>1 logitudinal cut sample</td><td>1 logitudinal cut sample</td><td>3 samples</td></tr>
<tr><td>1 burst test sample</td><td>1 burst test sample</td><td></td></tr>
<tr><td>3 normal samples</td><td>3 normal samples</td><td></td></tr>
<tr><td>Requalification laser and GTAW orbital weld</td><td>1 set according to ASM006, Rev. B</td><td>1 set according to ASM006, Rev. B</td><td></td></tr>
</table>

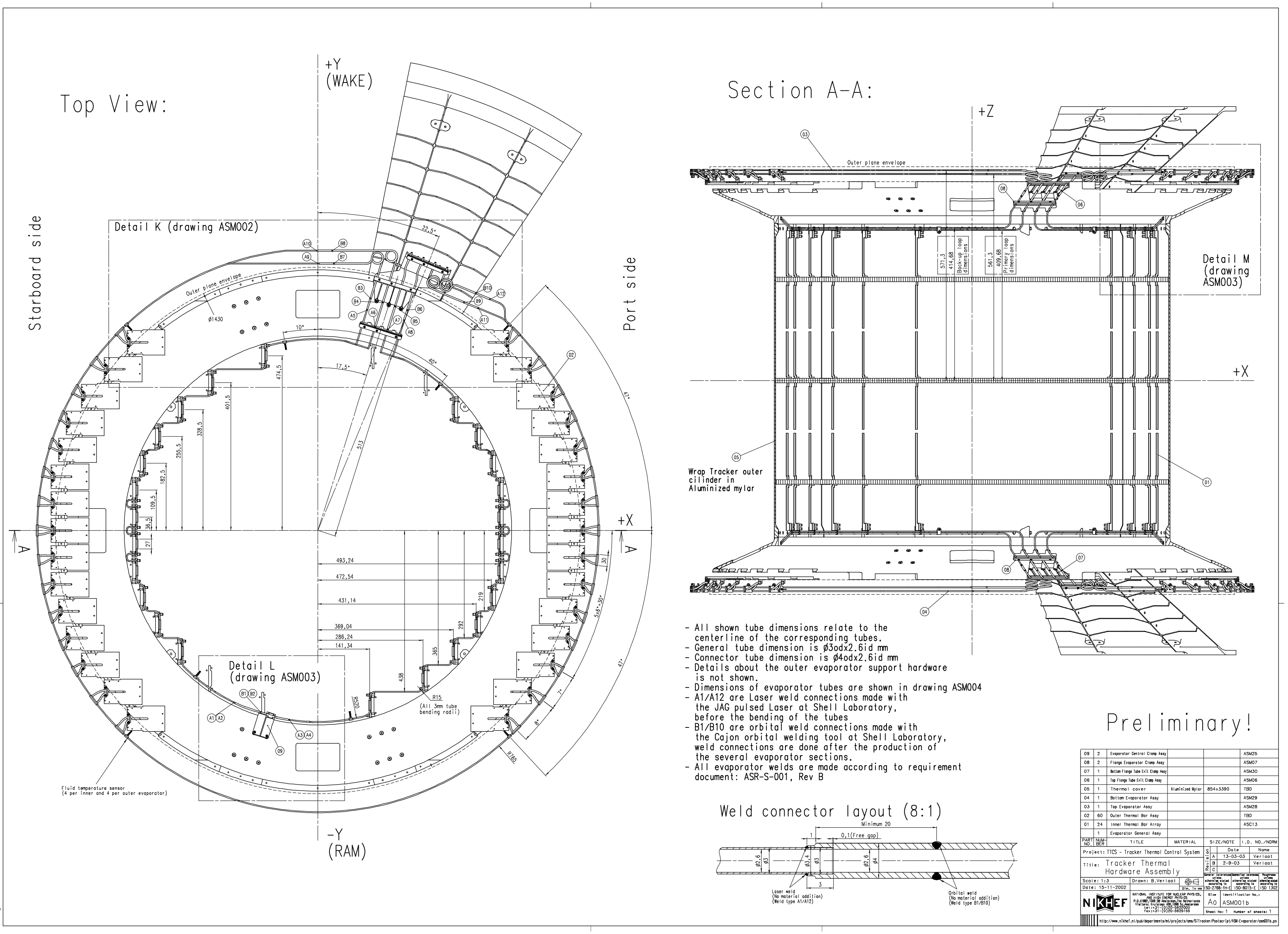
# Appendix

## *Appendix I: Applicable drawings*

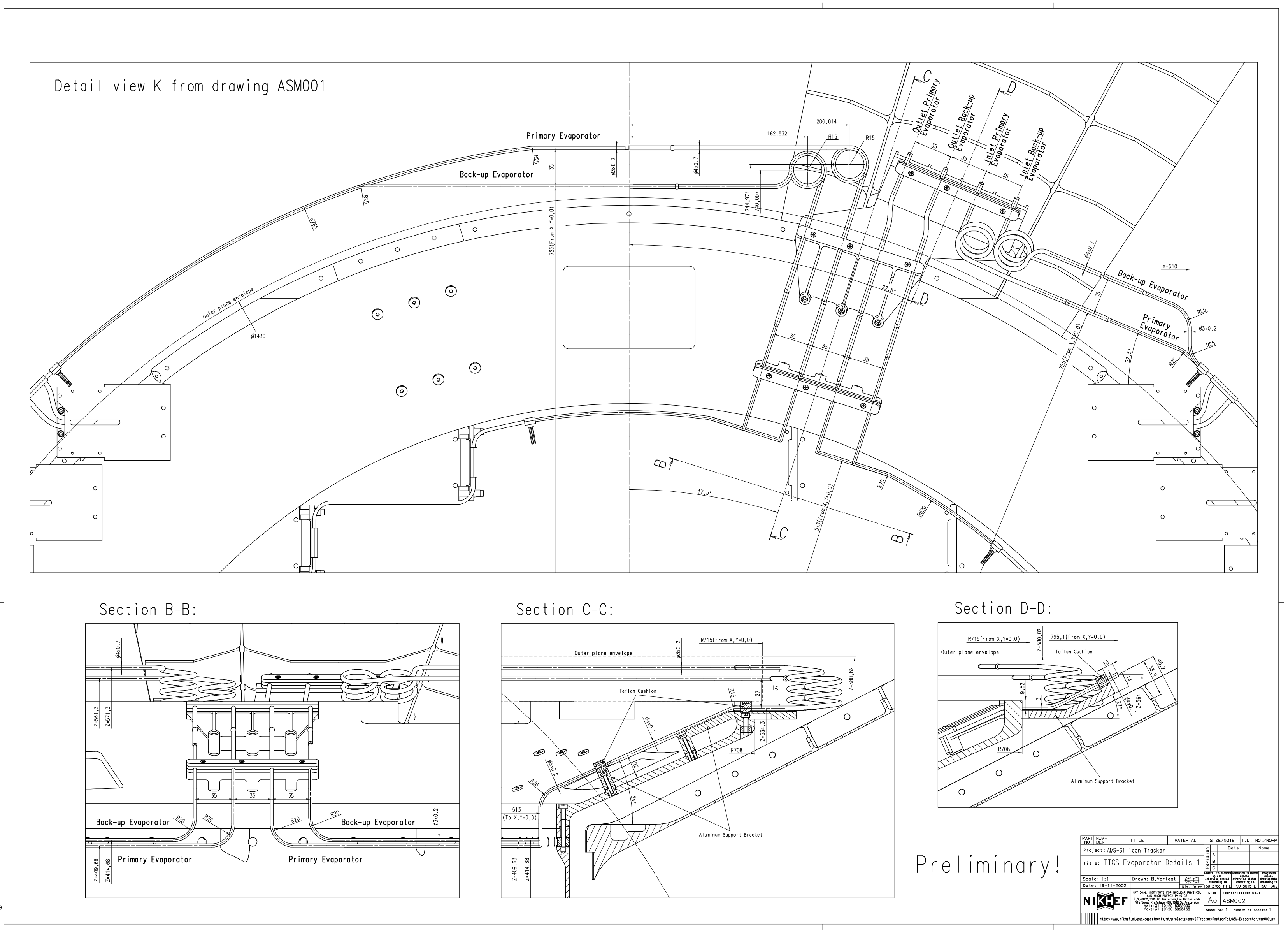
The listed drawings in this appendix can be downloaded in postscript format (A4) and HPGL format (Original size; A4,A3,A2,A1 or A0) at the following web location:

http://www.nikhef.nl/pub/departments/mt/projects/ams/SiTracker/EvaporatorDrawings.html

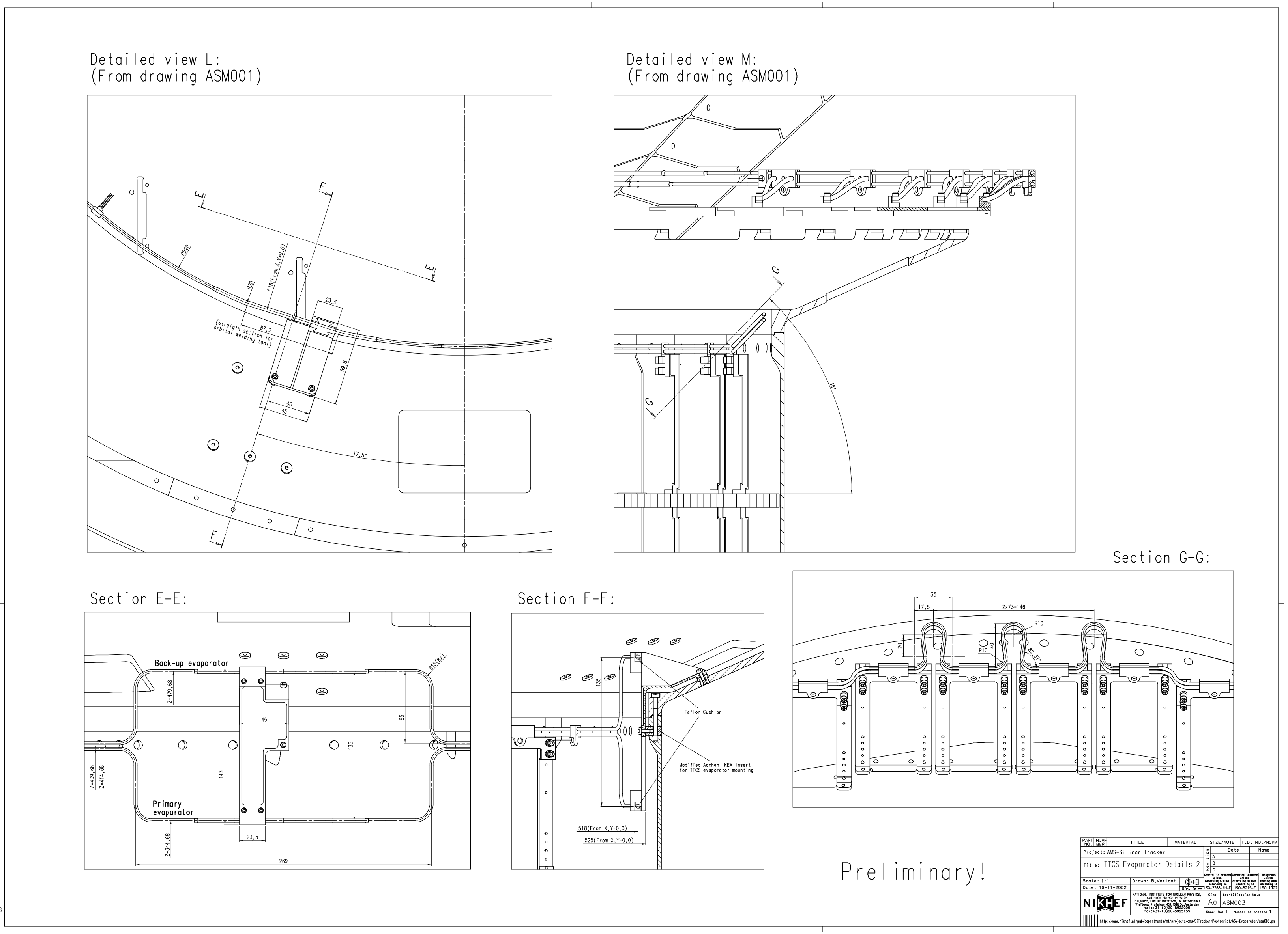
ASM001, Rev B.


Top View:
+Y
(WAKE)
-Y
(RAM)
+X
Starboard side
Port side
Detail K (drawing ASM002)
Detail L
(drawing ASM003)
Outer plane envelope
Fluid temperature sensor
(4 per inner and 4 per outer evaporator)
R15
(All 3mm tube bending radii)
Section A-A:
+Z
+X
Outer plane envelope
Detail M
(drawing ASM003)
Wrap Tracker outer cilinder in Aluminized mylar
- All shown tube dimensions relate to the centerline of the corresponding tubes.
- General tube dimension is ø3odx2.6id mm
- Connector tube dimension is ø4odx2.6id mm
- Details about the outer evaporator support hardware is not shown.
- Dimensions of evaporator tubes are shown in drawing ASM004
- A1/A12 are Laser weld connections made with the JAG pulsed Laser at Shell Laboratory, before the bending of the tubes
- B1/B10 are orbital weld connections made with the Cajon orbital welding tool at Shell Laboratory, weld connections are done after the production of the several evaporator sections.
- All evaporator welds are made according to requirement document: ASR-S-001, Rev B
Weld connector layout (8:1)
Minimum 20
0,1(Free gap)
Laser weld
(No material addition)
(Weld type A1/A12)
Orbital weld
(No material addition)
(Weld type B1/B10)
Preliminary!
09 | 2 | Evaporator Central Clamp Assy | | | ASM25
08 | 2 | Flange Evaporator Clamp Assy | | | ASM07
07 | 1 | Bottom Flange Tube Exit Clamp Assy | | | ASM30
06 | 1 | Top Flange Tube Exit Clamp Assy | | | ASM06
05 | 1 | Thermal cover | Aluminized Mylar | 854x3390 | TBD
04 | 1 | Bottom Evaporator Assy | | | ASM29
03 | 1 | Top Evaporator Assy | | | ASM28
02 | 60 | Outer Thermal Bar Assy | | | TBD
01 | 24 | Inner Thermal Bar Array | | | ASC13
 | 1 | Evaporator General Assy | | |
PART NO. | NUMBER | TITLE | MATERIAL | SIZE/NOTE | I.D. NO./NORM
Project: TTCS - Tracker Thermal Control System
Title: Tracker Thermal Hardware Assembly
Revision | Date | Name
A | 13-03-03 | Verlaat
B | 2-9-03 | Verlaat
C
Scale: 1:3
Drawn: B.Verlaat
Date: 15-11-2002
Dim. in mm
General tolerances unless otherwise stated according to ISO-2768-fH-E
Geometrical tolerances unless otherwise stated according to ISO-8015-E
Roughness unless otherwise stated according to ISO 1302
NATIONAL INSTITUTE FOR NUCLEAR PHYSICS, AND HIGH ENERGY PHYSICS
P.O.41882,1009 DB Amsterdam,The Netherlands
Visitors: Kruislaan 409,1098 SJ,Amsterdam
tel:+31-(0)20-5922000
fax:+31-(0)20-5925155
Size A0
Identification No.: ASM001b
Sheet No: 1 Number of sheets: 1
http://www.nikhef.nl/pub/departments/mt/projects/ams/SiTracker/Postscript/ASM-Evaporator/asm001b.ps

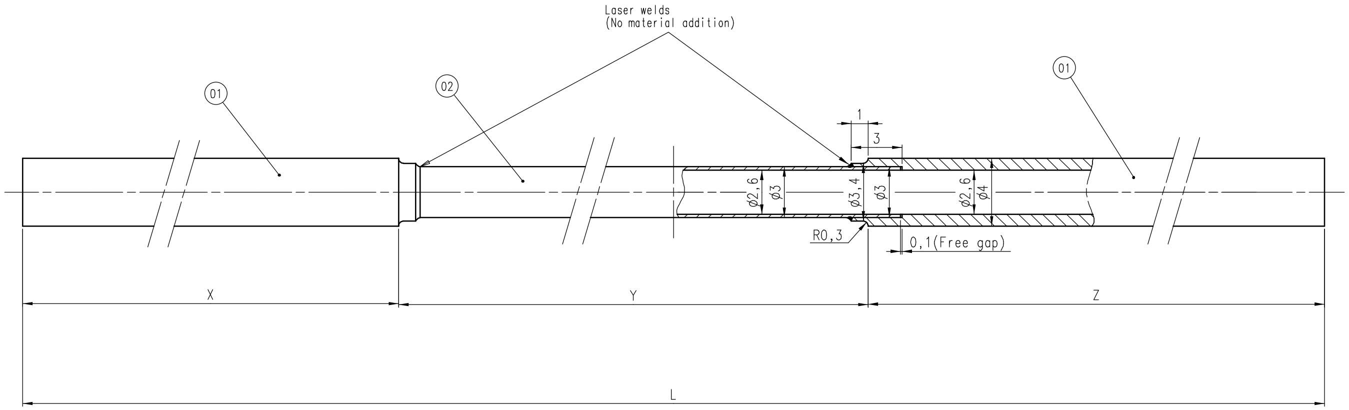
ASM002


Detail view K from drawing ASM001
Primary Evaporator
Back-up Evaporator
Outer plane envelope
Outlet Primary Evaporator
Outlet Back-up Evaporator
Inlet Primary Evaporator
Inlet Back-up Evaporator
Section B-B:
Section C-C:
Section D-D:
Teflon Cushion
Aluminum Support Bracket
Preliminary!
Project: AMS-Silicon Tracker
Title: TTCS Evaporator Details 1
Scale: 1:1
Date: 19-11-2002
Drawn: B.Verlaat
ASM002

ASM003.


Detailed view L:
(From drawing ASM001)
Detailed view M:
(From drawing ASM001)
Section E-E:
Back-up evaporator
Primary evaporator
Section F-F:
Teflon Cushion
Modified Aachen IKEA insert for TTCS evaporator mounting
Section G-G:
Preliminary!
Project: AMS-Silicon Tracker
Title: TTCS Evaporator Details 2
Scale: 1:1
Drawn: B.Verlaat
Date: 19-11-2002
ASM003

ASM004, Rev B.




| Title | ID number | X (mm) | Y (mm) | Z (mm) | L (mm) |
|---|---|---|---|---|---|
| Inner Ring Evaporator | ASM004-1 | 250 | 2056 | 250 | 2556 |
| Outer Ring Evaporator | ASM004-2 | 250 | 4326 | 250 | 4826 |
| Test weld | ASM004-3 | 100 | 100 | - | 200 |

Note 1: Material details in inspection certificate in appendix V of document ASR-S-001, Revision B.

WELD AND INSPECT PER NASA/JSC PRC-0010, CLASS B

The procedure described in document ASR-S-001 Revision B, 2 September 2003 (Requirements for the manufacturing and qualification of all the pressurized weld joints in the AMS-TTCS evaporator) shall be followed for the production of the TTCS evaporator welds.

| PART NO. | NUMBER | TITLE | MATERIAL | SIZE/NOTE | I.D. NO./NORM |
|---|---|---|---|---|---|
| 02 | | Connector Tube | CRES316L | Seamless, ⌀3x0.2mm Note 1 | Merinox |
| 01 | | Evaporator Tube | CRES316L | Seamless, ⌀4x0.7mm Note 1 | Merinox |

Project: TTCS - Tracker Thermal Control System

Title: Evaporator Tube Weld Connector Assy

| Revision | Date | Name |
|---|---|---|
| A | 11-3-03 | Verlaat |
| B | 2-9-03 | Verlaat |
| C | | |

Scale: 1:1 — Drawn: B.Verlaat — Date: 8-1-2003 — Dim. in mm

| General tolerances unless otherwise stated according to | Geometrical tolerances unless otherwise stated according to | Roughness unless otherwise stated according to |
|---|---|---|
| ISO-2768-fH-E | ISO-8015-E | ISO 1302 |

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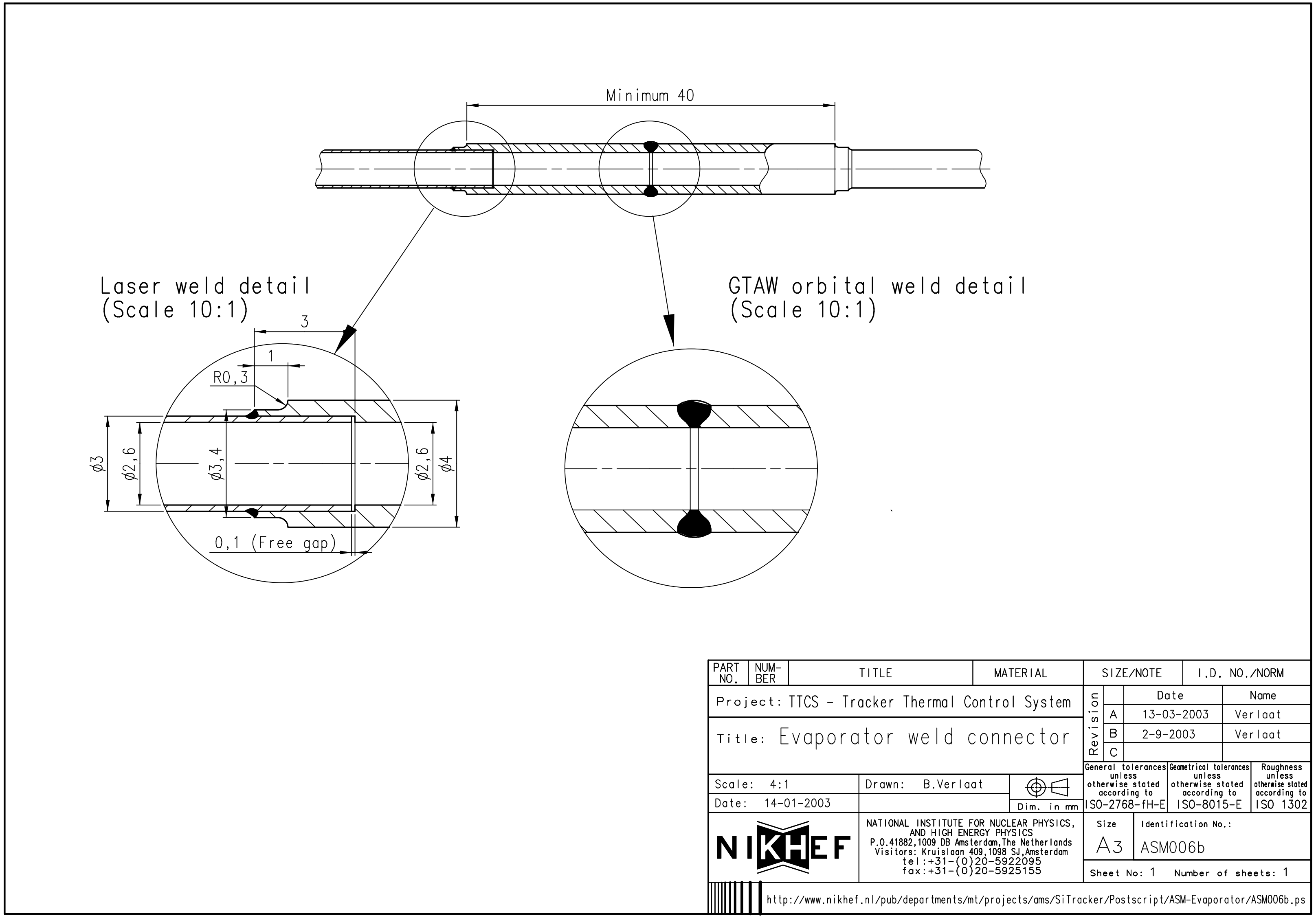
tel:+31-(0)20-5922095
fax:+31-(0)20-5925155

Size: A2 — Identification No.: ASM004b

Sheet No: 1 Number of sheets: 1

http://www.nikhef.nl/pub/departments/mt/projects/ams/SiTracker/Postscript/ASM-Evaporator/asm004b.ps

ASM006, Rev B



Minimum 40
Laser weld detail
(Scale 10:1)
3
1
R0,3
ϕ3
ϕ2,6
ϕ3,4
ϕ2,6
ϕ4
0,1 (Free gap)
GTAW orbital weld detail
(Scale 10:1)
PART NO.
NUM-BER
TITLE
MATERIAL
SIZE/NOTE
I.D. NO./NORM
Project: TTCS - Tracker Thermal Control System
Title: Evaporator weld connector
Revision
Date
Name
A 13-03-2003 Verlaat
B 2-9-2003 Verlaat
C
General tolerances unless otherwise stated according to ISO-2768-fH-E
Geometrical tolerances unless otherwise stated according to ISO-8015-E
Roughness unless otherwise stated according to ISO 1302
Scale: 4:1
Drawn: B.Verlaat
Date: 14-01-2003
Dim. in mm
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P.O.41882,1009 DB Amsterdam,The Netherlands
Visitors: Kruislaan 409,1098 SJ,Amsterdam
tel:+31-(0)20-5922095
fax:+31-(0)20-5925155
Size A3
Identification No.: ASM006b
Sheet No: 1
Number of sheets: 1
http://www.nikhef.nl/pub/departments/mt/projects/ams/SiTracker/Postscript/ASM-Evaporator/ASM006b.ps

## *Appendix II: E-mail conversations*

From: Bart Verlaat [mailto:bverlaat@nikhef.nl]
Sent: Friday, January 10, 2003 8:51 AM
To: RYBICKI, DANIEL (JSC-EM) (LM)
Cc: Trent Martin; Eric Perrin
Subject: TTCS welds,

Dear Daniel,

We are preparing the production of the TTCS evaporators. In July we talked about the welds we use in this piece of flight hardware. To be sure we are doing the right thing concerning production and verification, I like to summarize them and get your approval.

As you might remember we are welding a 4mmx0.7mm tube to a 3mmx0.2mm tube with a laser. These 4mm tube extensions we weld with a normal Cajon orbital welding apparatus to each other.

According to document PRC-0010 and to your comment on last years meeting, these welds are identified as Class B welds. This means that they are not dangerous and can only cause malfunctioning of the payload.

We agreed that we do only a proof test of 1.5x MDP on the flight hardware and a visual inspection. We agreed to make post and pre weld samples for extensive testing. The idea is that we make 5 pre welds and 5 post welds from which we cut 1 of the 5 for internal visible inspection and we do a 4xMDP burst test on another one. This will give us 3 remaining post and 3 remaining pre weld samples for NASA/LMCO to inspect. The welding tool settings will be monitored too.

For analyses purposes we will submit to you the longest unsupported length of a tube section with a weld and the maximum stresses at the welds due to lift-off.

To my understanding this is all we agreed upon to do for the welding certification. Is my understanding the right one? Please correct me when I'm wrong.

Have a nice weekend,

Greetings,
Bart

Date: Fri, 10 Jan 2003 14:59:50 -0600
From: "RYBICKI, DANIEL (JSC-EM) (LM)" <daniel.rybicki1@jsc.nasa.gov>
To: 'Bart Verlaat' <bverlaat@nikhef.nl>
Cc: Trent Martin <Trent.Martin@lmco.com>, Eric Perrin
<Eric.Perrin@physics.unige.ch>
Subject: RE: TTCS welds,

Hi Bart and Happy New Year,

I do recall our July conversation well and as agreed, for practical purposes to ensure safety, these welds can be stated as Class B welds. We also agreed that the Dye Penetrant requirement (Class B inspection) is NOT practical due to the size of these tubes and as agreed, a thorough visual inspection (use magnification) and proof pressure test of the welded system should be sufficient. Because this is essentially a departure to the written PRC-0010 requirement, let's agree that this email shall serve as documentation of our agreement (ref. 8.4 in PRC) and approval for this change (waiver approval).

With "proof pressure testing" being the assurance element that gives us a guarantee of a safe pressurized system, in addition, perhaps you may also want to consider performing (or maybe you already plan to do so) some form of "leak integrity" test such as pressure decay, helium sniff, or soap bubble test to ensure absolute functionality of the closed fluid system.

The pre- and post-weld test samples are fine however, as the PRC states, the weld parameters should be "bounded" by low and high settings (ref. 6.2.1.2 in PRC) to absorb any parameter fluctuations/adjustments that may occur during the fabrication welds. Let me suggest that the pre-weld samples be 5 each at low and high power level settings. From each set of 5, you can cut 1 to inspect I.D. and then mount that sample for metallographic examination, burst test another 1, and then send the other 3 here. Postweld samples are not required but are always considered "good show" of process robustness for the duration of the project. If you do choose to do these then I would suggest only making 3 or so total at a nominal setting, to save cost. So, to summarize, for qualification purposes you'll weld a minimum of 10 welds (5 at low and 5 at high power levels), visual inspect all 10 per PRC-0010 Class B, cut in half (longitudinally) 1 from each group for I.D. examination and metallography, burst test 1 from each group, and send the remaining to LMSO. In time, I would be interested to see the cross sectioned mounted samples and perhaps pictures/data from the burst samples.

The rest of the PRC requirements are pretty clear. I think with that, you should be ready.

Regards,

Dan Rybicki
Materials & Processes
Welding and Brazing Applications
LMSO-NASA/JSC - ES4

From: Bart Verlaat [mailto:bverlaat@nikhef.nl]
Sent: Tuesday, January 14, 2003 7:05 AM
To: RYBICKI, DANIEL (JSC-ES4) (LM)
Cc: Trent Martin; Eric Perrin; Bert Kaan
Subject: RE: TTCS welds,

Hi Dan,

Thanks for the clear info for our welding qualification procedure.

However I still have some questions.

The document which we follow as reference says in chapter 2.0 "Applicability" that this applies to GTAW and PAW processes. Essentially we weld to 4mmx0.7mm tubes together with the GTAW method. But these 4x0.7 sections are welded with a Nd-YAG pulsed laser to the 3mmx0.2mm tubes. Does this PRC-0010 document applies to our laser weld as well?

As you've seen in our July meeting, we have successfully made test samples. Reading PRC0010, It seems that before the production also these test welds should be qualified according to PRC-0010. This was not done those days. Is it anyhow possible for us to proceed with production welds? Or do we need a requalification according to PRC-0010 chapter:6.2.3?

For the production weld qualification we agree on your 10 January Email. As I understood well NASA/LMSO will perform the final inspections according to the AWS requirements. The only qualification we do is the visual inspection and proof pressure tests on the flight hardware and the burst pressure test on 1 sample of each group. I will let the manufacturer cut 1 sample of each group by wire spark cutting, but I like to suggest that the metallographic examination on the cut sample will also be done by NASA/LMSO. We do not have access to the AWS B2.1 document for evaluation.

In your mail you don't talk about the necessary documentation. As a minimum a WPS (Welding Procedure Specification) and a PRC (Procedure Qualification Record) are needed according to PRC-0010. I assume that this is also what you want from us. Do you have examples of this WPS and PRC for a similar weld application for us as a guideline? Maybe even a standard fill-out form is available.

You suggested in your mail to do leak integrity tests. Off course we already considered them. I'm thinking about doing helium leak tests on the individual components and pressure decay tests on larger assemblies.

Greetings,

Bart

Date: Fri, 17 Jan 2003 08:27:18 -0600
From: "RYBICKI, DANIEL (JSC-ES4) (LM)" <daniel.rybicki1@jsc.nasa.gov>
To: 'Bart Verlaat' <bverlaat@nikhef.nl>
Cc: Trent Martin <Trent.Martin@lmco.com>, Eric Perrin <Eric.Perrin@physics.unige.ch>, Bert Kaan <bert@nikhef.nl>
Subject: RE: TTCS welds,
Parts/Attachments: 21 KB, Application; 58 KB, Application; 79 KB, Application

Bart,
I think I can answer all your questions. In text, PRC-0010 does not apply to LASER welding but in logic, it certainly can. As should be obvious, the technical specifics of a certain welding process will be different when compared to another process but the "philosophy" (methodology) of qualifying and controlling the process is essentially the same and the methodology of verifying that the process gave good results is the same. The exact specifics of how this is done will vary from LASER to TIG or to whatever process.

No, we have never written a PRC for LASER welding because we do not employ the process here. Perhaps we need one though but that's for the long term. So for your application, let's apply some good judgment to what you have and go from there. And while I'm at it, I should commend you for being innovative and overcoming the difficulty you had with orbital TIG welding the small diameter, thin wall tubing in the manner in which you did (i.e., by LASER welding tube stubs to the ends to provide a much more easily orbital TIG welded close-out configuration). Innovations like this save money, time, and in my opinion are completely acceptable and deserve favorable mention.

The LASER welds we looked at this past summer looked to be of excellent quality so considering that, we can make an assumption that your vendor's process is in control for repeatability purposes. Metallurgy of this joint should be simple because there is no filler metal. To validate the integrity of this joint can be simply by proof testing. To accomplish this, just make some of your pre- and post-weld test samples sets from components that include the LASER welds in them. That way we can evaluate the LASER welds by visual exam, cross sectioning (for metallographic examination) and burst testing (please note the rupture location or take photographs of failed samples); all at the same time we do the orbital TIG welds. This would entail just making your samples longer to include the LASER welds. I don't think that all of them need to be in this configuration as that may induce undue costs to you but at least 1 for burst test and 1 for cross sectioning. I'll attach a sketch to better explain the intent.

Standard welding forms: No problem. See attached also. Please note that the sections titled "WELD SETTINGS" and "HEAT INPUT CONDITIONS" and "WELD SETUP" should be modified as required to accommodate the specific machine/equipment controls that you have. And for that matter, any part of the form should be changed at your discretion to accommodate your specific conditions. I made these sometime ago but they are basically MSPowerPoint copies of standard AWS paper forms and formats. Let me know if there's anything else I can help with. I hope I've answered everything.

Dan Rybicki

From: Bart Verlaat [mailto:bverlaat@nikhef.nl]
Sent: Wednesday, March 12, 2003 9:55 AM
To: DANIEL RYBICKI
Subject: Tube welding

Hi Dan,

Thanks for the connector info, I will study the application for our system.

About the welding. I have almost finnished the procedure for the welding as discussed last month. but I still have one question. We have to make pre weld samples on "limit low" and "limit high" heat settings.

How much is limit low and how much is limit high?

Greetings,

Bart

Date: Wed, 12 Mar 2003 16:44:51 -0600
From: "RYBICKI, DANIEL (JSC-ES4) (LM)" <daniel.rybicki1@jsc.nasa.gov>
To: 'Bart Verlaat' <bverlaat@nikhef.nl>
Subject: RE: Tube welding

Limt low and limit high is not defined in the spec in terms of quantitative amounts. It is entirely determined by the fabricator (you in this case). Our typical goal is to define the widest practical range (i.e., low range being just above the point where it will not penetrate the wall thickness and the high range just below the point where it begins to make unsatisfacory welds) we can find that will allow us the latitude to make in process adjustments to accomodate most material and/or configuration variances. I usually try to achieve +/- 10% of the nominal current setting. Just as an example, welding at about 33 amps (nominal setting) on 0.030" wall tube, we will attempt to certify at a low of 30 amps and a high of 36 amps. Obviously, the thinner the tube wall, the smaller the range will be; maybe even as low as just a 1 amp deviation from the nominal setting.

I hope this helps,

Dan Rybicki
Materials & Processes
Welding and Brazing Applications
LMSO-NASA/JSC - ES4
(281) 244-5181 Phone
(281) 527-6581 Pager
(281) 244-1301 Fax
daniel.rybicki@jsc.nasa.gov

# *Appendix III: WPS and PQR form examples*

**YOUR COMPANY/ORGANIZATION NAME goes here**

## ORBITAL TUBE ARC WELDING PROCEDURE SPECIFICATION (WPS)

WPS Number ____________ Revision ________ Company / Organization ____________________

Supporting PQR no.(s) ____________________ Welding Process(es) Automatic Orbital Tube Gas Tungsten Arc

### BASE and FILLER METAL :

Material number ____________ Group ________ to Material number ____________ Group ________

Material spec., type, and grade ____________ to Material spec., type, & grade ____________

Base metal thickness range ____________

Pipe / Tube diameter ________ Wall thickness ________

Filler metal F No. ______ AWS Class & Spec. ________

Consumable Insert, AWS Class & Spec ________

### WELDING SET-UP :

Power Supply (Model) ____________

Weld Head(s) ____________

Joint Position(s) ____________

Tungsten type ________ Diameter ______ Arc gap ______

Tip diameter ________ Tip angle ________

Weld direction ________ Pulse Mode ________

### WELD SETTINGS :

Start current (amps) ________ Upslope (sec.) ________

Level Slope Time (sec.) ________ Downslope (sec.) ________

Start Delay (sec.) ________ Override (%) ________

Finish Current (amp) ________ Fixture Speed (RPM) ________

Weld Timer (on/off) ________ Step Mode (on/off) ________

Wire Mode (on/off) ________

### NOMINAL HEAT INPUT CONDITIONS :

| Level Number | Weld Time (sec.) | Allowable Current (amps) Settings HIGH +5% | Nominal | -5% | LOW Nominal | Pulse Rate (pps) | Pulse Width Nominal |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |

### TECHNIQUE :

Joint cleaning ____________

Other ____________

____________

### GAS :

Torch/Head gas(es) ____________

% Composition ____________ Flow Rate ________

Prepurge Time ________ Postpurge Time ________

Backing gas(es) ____________

% Composition ____________ Flow rate ________

Prepurge Time ________ Postpurge Time ________

### PRE and POSTWELD HEAT :

Preheat temperature minimum ____________

Preheat temperature maximum ____________

Interpass temperature minimum ____________

Interpass temperature maximum ____________

Postweld HeatTreatment ____________

### JOINT DESIGN :

Joint type ____________

Groove angle ______ Radius ______ Land ______

Root opening ______ Size of fillet ________

Socket weld pull-back ____________

**SETUP SKETCH -**

---

We certify that this welding procedure and schedule were qualified in accordance with the requirements of NASA / JSC PRC-0010.

Prepared By ____________ Org. ________ Date ________

Approved By ____________ Org. ________ Date ________

YOUR COMPANY/ORG name goes here



# ORBITAL TUBE GAS TUNGSTEN ARC WELDING PROCEDURE QUALIFICATION RECORD (PQR)

PQR Number ____________ Revision ________ Company / Organization ______________

Supporting WPS no.(s)______________ Welding Process(es)____Automatic Orbital Tube Gas Tungsten Arc

**BASE and FILLER METAL :**

Material number ____________ Group ______ to Material number ____________ Group ______

Material spec., type, and grade______________ to Material spec., type, & grade ______________

Base metal thickness range______________

Pipe / Tube diameter________ Wall thickness________

Filler metal F No. ______ AWS Class & Spec. ________

Consumable Insert, AWS Class & Spec. ________

**GAS :**

Torch gas(es) ______________

% Composition __________ Flow Rate ______

Prepurge Time ________ Postpurge Time______

Backing gas(es) ______________

% Composition__________ Flow rate______

Prepurge Time ________ Postpurge Time______

**WELDING SET-UP :**

Power Supply (Model) ______________

Weld Head(s)______________

Joint Position(s)______________

Tungsten type________ Diameter______ Arc gap______

Tip diameter ________ Tip angle ________

Weld direction__________ Pulse Mode ________

**PRE and POSTWELD HEAT :**

Preheat temperature minimum______________

Preheat temperature maximum______________

Interpass temperature minimum ______________

Interpass temperature maximum ______________

Postweld HeatTreatment______________

**WELD SETTINGS :**

Start current (amps) ________Upslope (sec.) ________

Level Slope Time (sec.)________Downslope (sec.) ________

Start Delay (sec.)________Override (%) ________

Finish Current (amp)________Fixture Speed (RPM) ______

Weld Timer (on/off) ________ Step Mode (on/off) ______

Wire Mode (on/off) ________ Finish Current ________

**JOINT DESIGN :**

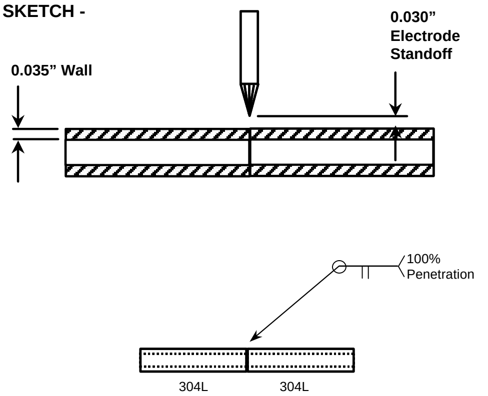
Joint type______________

Groove angle______ Radius______ Land ______

Root opening ______ Size of fillet__________

Socket weld pull-back ______________

**SKETCH -**




**NOMINAL HEAT INPUT CONDITIONS :**

| Level Number | Weld Time (sec.) | Allowable Current (amps) Settings HIGH +5% | HIGH Nominal | HIGH -5% | LOW Nominal | Pulse Rate (pps) | Pulse Width Nominal |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

**TECHNIQUE :**

We certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of the NASA / JSC PRC-0010.

Qualifier : ______________ Reviewed by : ______________

Date : ______________ Approved by : ______________

## PROCEDURE QUALIFICATION RECORD ( PQR ) for ORBITAL TUBE GAS TUNGSTEN ARC WELDING



**PQR No.** ______________

**TENSILE TEST SPECIMENS :**

Type : ______________ Tensile specimen size : ______________ Area: ______________

Groove ( ) Socket Lap w/fillet ( )

Tensile test results : (minimum required UTS : ______________ psi)

| Specimen No. | O.D., in.[(a)] | Wall Thkns, in. | Area, $in^2$ | Max Load, lbs | $F_{tu}$, psi | Type Failure/Loc |
|---|---|---|---|---|---|---|
| | | | | | | |

**GUIDED BEND TEST SPECIMENS - SPECIMEN SIZE:** ______________

| Type | Result | Type | Result |
|---|---|---|---|
| | | | |

**MACRO - EXAMINATION RESULTS :**

______________

**IMPACT TEST SPECIMENS**

Type : ______________ Size : ______________

Test temperature : ______________

Specimen location : WM = weld metal; BM = base metal; HAZ = heat - affected zone

Test results :

| Welding position | Specimen location | Energy absorbed ( ft. - lbs. ) | Ductile fracture area ( percent ) | Lateral expansion ( mils ) |
|---|---|---|---|---|
| | | | | |

**IF APPLICABLE** **RESULTS**

| | | |
|---|---|---|
| Hardness tests : ( ) Values ______________ | Acceptable ( ) | Unacceptable ( ) |
| Visual Inspection ( ) ______________ | Acceptable ( ) | Unacceptable ( ) |
| Torque ( ) psi ______________ | Acceptable ( ) | Unacceptable ( ) |
| Proof test ( ) Method ______________ | Acceptable ( ) | Unacceptable ( ) |
| Chemical analysis ( ) ______________ | Acceptable ( ) | Unacceptable ( ) |
| Non-destructive exam ( ) Process ______________ | Acceptable ( ) | Unacceptable ( ) |
| Other ______________ | Acceptable ( ) | Unacceptable ( ) |

Mechanical testing conducted by (Company)______________ Lab No.______________

We certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of the NASA / JSC PRC-0010.

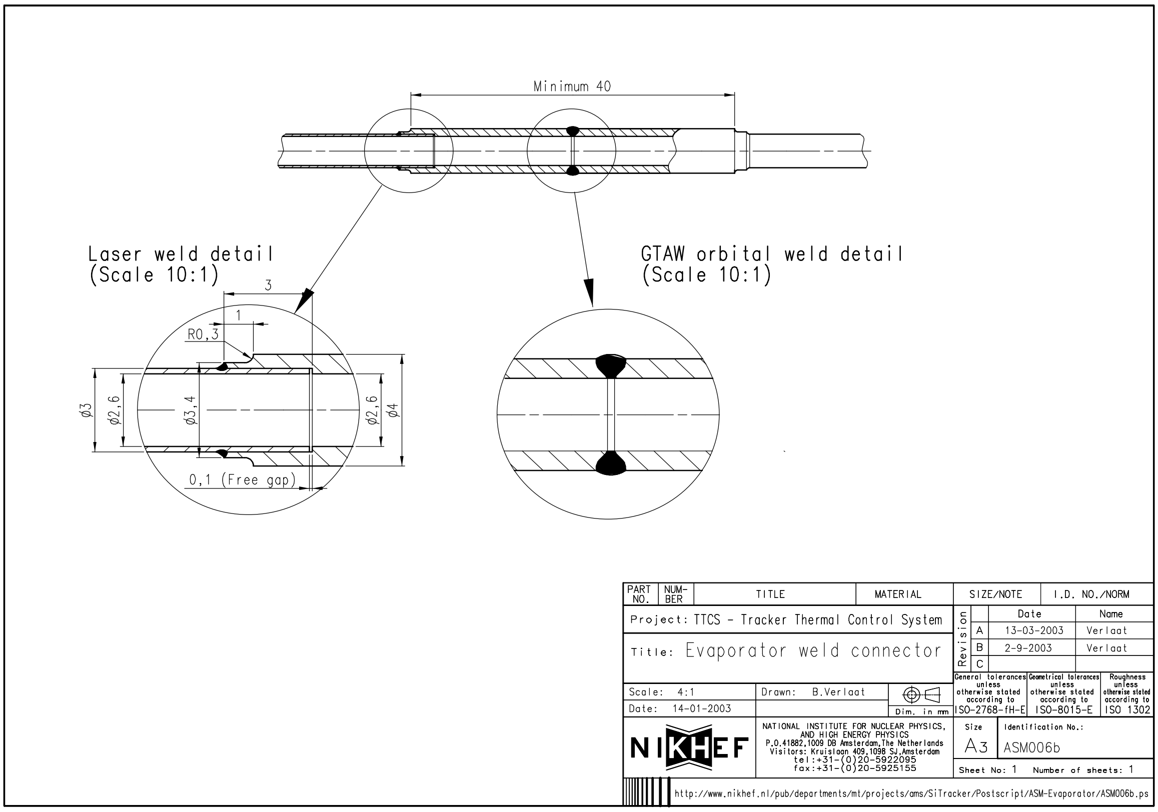
Qualifier : ______________ Reviewed by : ______________

Date : ______________ Approved by : ______________

These forms are just for reference, non relevant issues can be deleted and applicable properties and tests shall be added.

## *Appendix IV: Weld procedure summary*

### A: Requalification of the welding procedure.



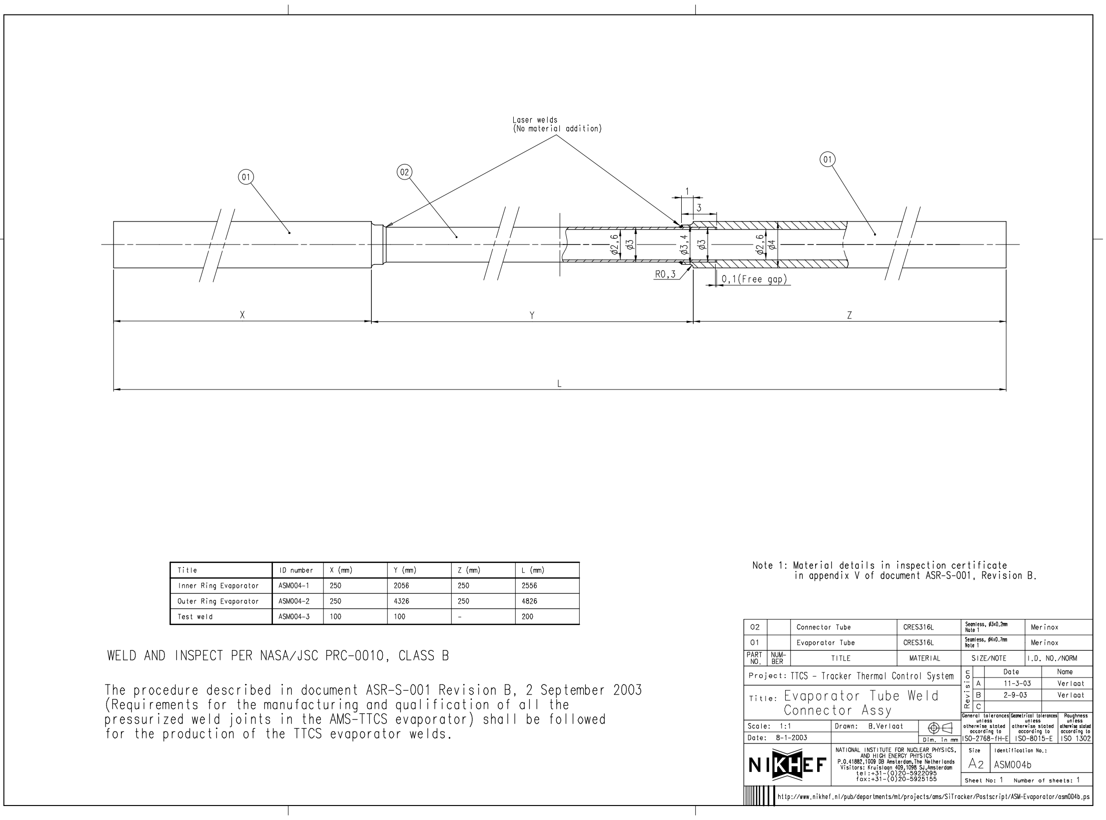

**A1: Re-qualification weld-sample according to ASM006, Rev. B**

- 1x low-limit (of-which: 1 longitudinal cut)
- 1x high-limit (of-which: 1 longitudinal cut)
- 1x nominal (of-which: 1 longitudinal cut)

**A2: Definition of WPS**

**A3. Approval of WPS, and permission of go-ahead from NIKHEF / NASA for flight hardware production.**

## B: Laser weld flight hardware production.




**B1. Pre-weld laser welding according to ASM004-3, Rev. B.**

- 5x low-limit (of-which: 1 longitudinal cut, 1 burst)
- 5x high-limit (of-which: 1 longitudinal cut, 1 burst)

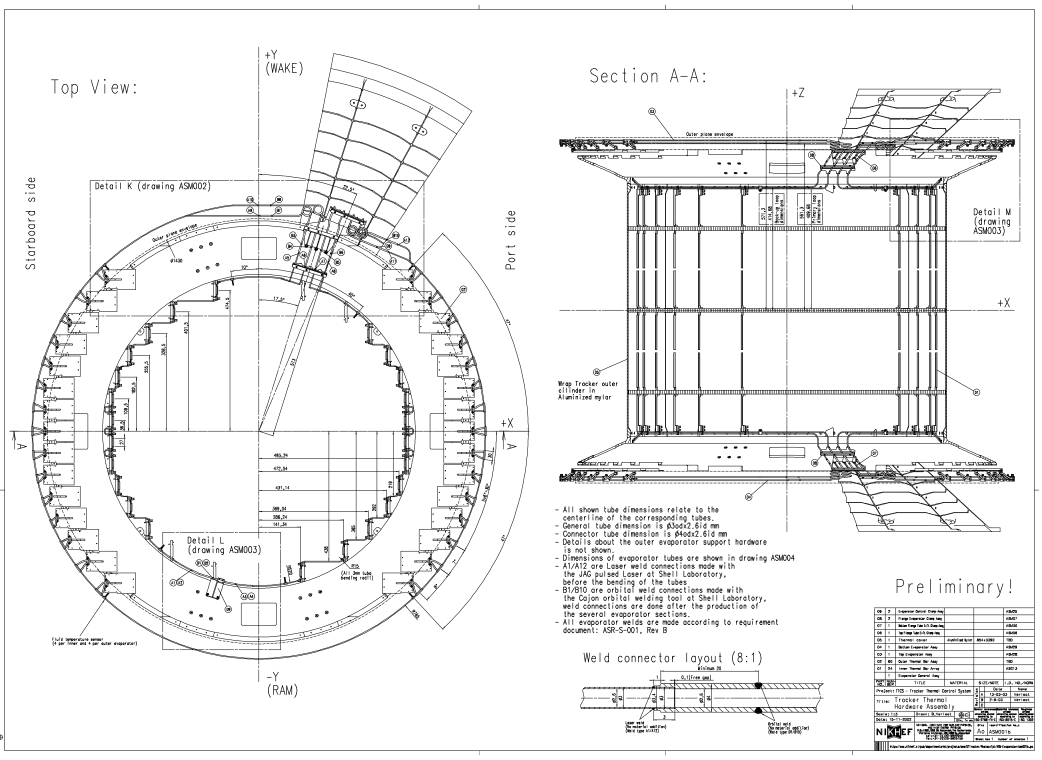
**B2. Flight hardware production tubes:**

- 16x dimensions according ASM004-1, Rev. B with nominal weld setting (of-which: 16x proof pressure tested with pure nitrogen @ 240 bar)
- 8x dimensions according ASM004-2, Rev. B with nominal weld setting (of-which: 8x proof pressure tested with pure nitrogen @ 240 bar)

**B3. Post-weld laser welds according to ASM004-3, Rev. B.**

- 3x low-limit
- 3x high-limit

# C: Orbital welding of complete assembly after assembly at NIKHEF.




**C1. Pre-weld orbital welds on Ø4x0.7mm tube (Length =TBD).**

- 5x low-limit (of-which: 1 longitudinal cut, 1 burst)
- 5x high-limit (of-which: 1 longitudinal cut, 1 burst)

**C2. Flight hardware orbital welds:**

- 10 welds on top evaporator assembly (ASM001/ASM28)
  (of-which 1x proof pressure test on complete assembly with pure nitrogen @ 240 bar)
- 10 welds on bottom evaporator assembly (ASM001/ASM29)
  (of-which 1x proof pressure test on complete assembly with pure nitrogen @ 240 bar)

**C3. Post-weld orbital welds on Ø4x0.7mm tube.**

- 3x low-limit
- 3x high-limit

## *Appendix V: Tube material certificates.*

MERINOX

STAINLESS TUBES

**Merinox b.v.**
*Industrieterrein Hoogendijk:*
Kleine Beer 16, 2952 AS Alblasserdam
Postbus 23, 2950 AA Alblasserdam
The Netherlands
Tel (31) 078-691 78 00
Fax (31) 078-693 16 30
E-mail: info@merinox.nl
Website: http://www.merinox.nl

NIKHEF
Kruislaan 409
1098 SJ Amsterdam
the Netherlands
T.a.v. Bart Verlaat

**PACKING LIST**
Packing list no. 20031585
Date : 25-06-03

Orderno. : 20030454
Account no. : 5945
Client reference : 00032924

Payment terms : 30 days nett
Delivery terms : Carriage Paid To
Handled by : Githa Stahlie

| Quantity | Unit | Description | Heatno. |
|---|---|---|---|
| 152,50 | Mtr. | St.st.smls. capillary tube Wst. 1.4404 acc. DIN 17458 D4/T3 annealed Size: 3,00 x 0,20 mm | 453768 327.63 |
| 150,20 | Mtr. | St.st.smls. capillary tube Wst. 1.4404 acc. DIN 17458 D4/T3 annealed Size: 4,00 x 0,70 mm Alles op lengtes van min. 5 m | 453768 236.00 |
| 2,00 | Pcs. | Certificates 3.1.B | |
| 1,00 | Pcs. | Packingscosts | |
| 1,00 | Pcs. | Freightcosts not applicable | |

CERTIFICATES

Netto weigth 10,85

UTI

| Abnahmeprüfzeugnis<br>Inspection Certificate | DIN<br>EN 10204 / 3.1 B | Zeugnis - Nr. 23253 |
|---|---|---|

UTI-SFM Feinmechanik GmbH, Staatsstrasse 5, D-97773 Aura

Merinox B.V.
Postfach 23

NL-2950 Alblasserdam

| | |
|---|---|
| **Kundenauftrag:** Your order: | 20030089 vom 20.02.03 |
| **Unser Auftrag** Our order: | CF000680 |
| **Lieferbedingung:** Terms of Delivery: | Lt. Auftragsbestätigung |
| **Lieferzustand:** Delivery state: | geglüht |

**Besondere Vereinbarungen:**
Special terms:
Nahtlose Rohre gem. DIN 17458 Pk. 1, außer Punkt 5.3.2 und 6.3.1.6 (Verwechslungsprüfung und ohne Druckprüfung)

**Prüfgegenstand: Nichtrostende Rohre / Rohrformteile**
Object Stainless steel tubes / fittings

**Werkstoff:**
Material: 1.4404 nahtlos

| **Position** Item | **Menge:** Quantity | **Abmessung (mm)** size (mm) | **Toleranzen** Tolerances | |
|---|---|---|---|---|
| 1 | 4,46 kg = 332 m | 3,00 mm Ad. x 0,20 mm Wdd. | D4 T3 | |

**Mechanische Werte / Mechanical Properties**

| **Position** Item | **Zugfestigkeit** Tensile strength Rm N/mm² | **Streckgrenze** Yield strength Rp 0,2 N/mm² | **Dehnung** Elongation % | **Härteprüfung** Hardness Vickers 0,5 | **Dichtheitsprüf.** Leak proof test bar | **Rauhigkeit.** Roughness my | |
|---|---|---|---|---|---|---|---|
| 1 | 653 | 358 | 67,43 | | | | |
| 2 | 655 | 373 | 69,34 | | | | |

**Chemische Zusammensetzung des Einsatzmaterials**
Chemical composition (according to works certificate of steel mill)

**Schmelz - Nr.:**
Cast No.: 453768

| C % | Si % | Mn % | P % | S % | Cr % | Mo % | Ni % | Ti % | Fe % | Al % | N % | Cu % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0,018 | 0,390 | 1,700 | 0,032 | 0,008 | 17,01 | 2,05 | 11,38 | | | | 0,063 | 0,30 |

**Ringaufdornversuch:**
Ring expansion test:

**Kennzeichnung:**
Marking:

**Sicht- und Maßkontrolle:**
Visual inspection and control of dimension: o.B.

**Andere Prüfungen:**
Other tests:

**UTI-SFM Feinmechanik GmbH**
Zertifiziert nach DIN EN ISO 9002: 1994
Qualitätsstelle

97773 Aura, 08.05.03

Abnahme:

Werkssachverständige

**Wir bestätigen, daß die oben aufgeführten Rohre den Lieferbedingungen entsprechend geprüft u. in Ordnung befunden wurden.**
It is certified that the tubing listed as above has been tested in accordance with the terms of delivery and found satisfactory.

VD-65-3 (QS) Änderung: d Elektronisch erstelltes Formular

| Abnahmeprüfzeugnis<br>Inspection Certificate | DIN<br>EN 10204 / 3.1 B | Zeugnis - Nr. 23277 |
|---|---|---|

| | |
|---|---|
| UTI-SFM Feinmechanik GmbH, Staatsstrasse 6, D-97773 Aura<br><br>Merinox B.V.<br>Postfach 23<br><br>NL-2950 Alblasserdam | Kundenauftrag:<br>Your order: 20030089 vom 20.02.03 |
| | Unser Auftrag<br>Our order: CF000680 |
| | Lieferbedingung:<br>Terms of Delivery: Lt. Auftragsbestätigung |
| | Lieferzustand:<br>Delivery state: geglüht |
| Prüfgegenstand: Nichtrostende Rohre / Rohrformteile<br>Object Stainless steel tubes / fittings | Besondere Vereinbarungen:<br>Special terms:<br>Nahtlose Rohre gem. DIN 17458 Pk. 1, außer Punkt 5.3.2 und 6.3.1.6 (Verwechslungsprüfung) |
| Werkstoff:<br>Material: 1.4404 nahtlos | |

| Position<br>Item | Menge:<br>Quantity | Abmessung (mm)<br>size (mm) | Toleranzen<br>Tolerances | |
|---|---|---|---|---|
| 2 | 12,98 kg =<br>236 m | 4,00 mm Ad. x<br>0,70 mm Wdd. | D4<br>T3 | |

**Mechanische Werte / Mechanical Properties**

| Position<br>Item | Zugfestigkeit<br>Tensile strength<br>Rm N/mm² | Streckgrenze<br>Yield strength<br>Rp 0,2 N/mm² | Dehnung<br>Elongation<br>% | Härteprüfung<br>Hardness<br>Vickers 0,5 | Dichtheitsprüf.<br>Leak proof test<br>bar | Rauhigkeit.<br>Roughness<br>my | |
|---|---|---|---|---|---|---|---|
| 1 | 668 | 319 | 56,96 | | | | |
| 2 | 632 | 373 | 65,07 | | | | |

**Chemische Zusammensetzung des Einsatzmaterials**
Chemical composition (according to works certificate of steel mill)
**Schmelz - Nr.:** Cast No.: 453768

| C % | Si % | Mn % | P % | S % | Cr % | Mo % | Ni % | Ti % | Fe % | Al % | N % | Cu % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0,018 | 0,390 | 1,700 | 0,032 | 0,008 | 17,01 | 2,05 | 11,38 | | | | 0,063 | 0,30 |

**Ringaufdornversuch:**
Ring expansion test:

**Kennzeichnung:**
Marking:

**Sicht- und Maßkontrolle:**
Visual inspection and control of dimension: o.B.

| | |
|---|---|
| **Andere Prüfungen:**<br>Other tests: | **UTI-SFM Feinmechanik GmbH**<br>Zertifiziert nach DIN EN ISO 9002: 1994<br>Qualitätsstelle |
| | 97773 Aura, 16.05.03 |
| | Abnahme:<br>Werkssachverständige |

**Wir bestätigen, daß die oben aufgeführten Rohre den Lieferbedingungen entsprechend geprüft u. in Ordnung befunden wurden.**
It is certified that the tubing listed as above has been tested in accordance with the terms of delivery and found satisfactory.

VD-85-3 (QS) Änderung: d    Elektronisch erstelltes Formular